# ACIDIC PRECIPITATION IN ONTARIO STUDY

## THE ECONOMICS OF ACID PRECIPITATION

## ONTARIO'S SOCIO - ECONOMIC

## RESEARCH PROGRAM

API 007/82



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Ministry of the Environment
Ontario

The Honourable
Keith C. Norton, Q.C.,
Minister

Gérard J. M. Raymond
Deputy Minister

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by

Jack A. Donnan

Policy and Planning Branch
Ontario Ministry of Environment
135 St. Clair Avie. W.
Toronto, Ontario, Canada M4V 1P5

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A.P.I.O.S. Coordination Office
Ontario Ministry of Environment
6th Floor, 40 St. Clair Ave. W.
Toronto, Ontario, Canada M4V 1M2
Project Coordinator: E. W. Piché

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# THE ECONOMICS OF ACID PRECIPITATION ONTARIO'S SOCIO-ECONOMIC RESEARCH PROGRAM

## INTRODUCTION

Very few problems consist of absolutes anymore. There is really no black or white; just a lot of gray, and we often have to make the best of a bad situation. This is the type of situation we face concerning many environmental problems. It is not simply a question of having pollution or not having pollution. It is a choice of how much pollution we are prepared to endure; or how much are we willing to give up, in cash or kind, for more pollution control or for actions to offset pollution effects? With such choices, it often seems the best we can do is to cut our losses.

Acid precipitation and the uncertainties that surround it is an issue that presents government leaders in Canada with some particularly difficult and unpleasant choices. These choices constitute a double dilemma for Canada and some of its provinces.

First of all, acid deposition of both wet and dry acidic substances can result in environmental damages and effects which are slow to manifest themselves, difficult to detect, hard to protect against and probably irreversible. These characteristics present decision-makers in the U.S. and Canada with two broad choices regarding major existing air pollution sources:

(a) initiation of intensive $SO_2$ and $NO_x$ emission control and abatement efforts to prevent future environmental damages but with the risk of bearing unnecessarily high costs in some locations or sectors.

(b) deferment of abatement actions until the effects are fully known and understood with the risk of waiting too long to save irreplaceable natural resources.

The second dilemma that confronts Canada, and Ontario in particular, concerns the U.S. actions with respect to $SO_2$ and $NO_x$ abatement. If the U.S. does not undertake abatement, Ontario and other Canadian provinces will have to decide among the following:

(a) unilateral imposition of $SO_2$ and $NO_x$ abatement on sources within their own jurisdictions with the risk that acid precipitation and its effects will not be substantially reduced.

(b) shifting resources to "defensive actions" such as lake liming or more intensive fisheries management programs, in an effort to protect sensitive ecosystems or to offset acidification damages.

(c) both of the above.

In addition, although acid precipitation enjoys the highest priority in some provinces and by the federal government, it is not the only environmental problem with which we must deal. It is important, therefore, to determine how much of our limited resources (money, manpower and time) should be devoted to acid precipitation and its resolution.

Economics is primarily concerned with principles and procedures for allocating society's limited resources among mankind's limitless wants. An understanding of the economic implications of acid precipitation and its control can, therefore, help to determine how much control and abatement is socially desirable as well as to design policies aimed at resolving the problem.

In this paper, the reasons why the Ontario Government has undertaken an economic research program as part of its overall acid precipitation research effort will be set out. Then a description of the investigations, their objectives and the methodological approaches used in these studies will be presented. Some of the key findings of our work to date will be discussed followed by some comments on where we are going from here.

In addition to describing the Ontario research program, this paper is intended to show how we have approached some of the important conceptual and methodological problems concerned with these investigations. The primary objective of these studies is the development of sound methods for measuring and assessing the costs and benefits of acid rain and its control. Ultimately, we hope to produce quantitative estimates of the benefits of pollution control that are complete, that can be understood by both the public and by administrators and which are credible to all parties involved in the issue.

## II. WHY ECONOMIC STUDIES HAVE BEEN UNDERTAKEN

Some of our colleagues who are working on this issue believe that physical and biological studies of acid precipitation effects will reveal the amount of "reductions in the air pollutant deposition rates - which would be necessary to protect identified sensitive areas" (U.S. Canada, Impact Assessment, Feb. 1981, p. P-ii). On the other hand, some of those who are studying the sources of the $SO_2$ and $NO_x$ emissions, which are the precursors to acid precipitation, suggest that emission reductions will be determined primarily by the cost of the abatement technology. The degree of emission control, they argue, will depend on what "will be politically acceptable, and technically practicable for different fuels". (U.S. Canada, Engineering, Costs and Emissions, Jan. 1981, p. 132).

However, a singular application of one or the other of these two approaches will not, by themselves, yield unambiguous objectives or targets for precursor emission controls or acid deposition. The various receptor categories and natural features, such as fisheries, forests and crops, that are affected by acid fallout will all have different sensitivities to the pollutants, hence different threshold levels of deposition that would protect them. Moreover, without additional information, it is not possible to compare the various physical effects and make defensible judgement about which things ought to be protected first and which are of least concern.

By the same token, information about the costs of control and the impacts of such costs in the economy are necessary but not sufficient to make unequivocal judgements about how much money and effort ought to be devoted to abatement or environmental protection efforts.

Economic principles provide a framework and explicit criteria for making these kinds of choices. Thus, in order that efforts and programs intended to reduce acid precipitation or protect natural resources from its effects are economically efficient, the benefits of such actions should be equal to or greater than the associated costs. Stated more generally, a program or level of effort is economically efficient if, over the long run, "gainers" or those who benefit from the programs, could (though not necessarily be required to do so) compensate producers (those who provide the

resources to implement the program) and any "losers" (those who are made to feel worse off as a result of the program).

Benefits include both private benefits and public benefits. Private benefits are the beneficial consequences of the program that accrue to individuals, especially those who bear the costs. If an $SO_2$ emitter can recover saleable by-products as a result of reducing its $SO_2$ emissions, this is a private benefit. In a broader sense, recreational fishing is a private benefit since the enjoyment accrues only to the fisherman and the activity of one fisherman can potentially detract from another fisherman's enjoyment.

Public benefits are those which can be enjoyed by one person without affecting its availability and quality to other people. Another important feature is that those who bear the costs of an environmental program seldom obtain any remuneration for public benefits. Viewing fish and wildlife, knowing that fish will be available for future use or for future generations or the preservation of ecosystems for future study and for genetic material are all valuable to people and are examples of public benefits.

Another useful distinction may be made between use and non-use benefits. Langford and Cocheba (1978) discuss this classification in the context of wildlife and note that it is roughly equivalent to the private and public benefit dichotomy.

Similarly, public, as well as private, costs may be associated with the control program. Private costs are the labour, raw materials, energy and other inputs required to implement the program. Business closures, and losses of employment can result in increases in public assistance payments as well as stress to the families of those laid off. Public assistance and social stress associated with unemployment are considered to be public costs.

In addition to economic efficiency, the distribution of benefits and costs is of great concern with respect to public investment programs and projects, especially environmental programs. Thus, we want to know how the costs and benefits are distributed among economic sectors, social groups, regions, over time, and perhaps even among generations. This involves an assessment of the economic impacts of the benefits and costs of the programs. Economic impacts, as measured by changes in expenditure or income, are not generally considered to be benefits or costs of the program. This is because an

increase in income or expenditure to one sector or location is often perfectly offset by a decrease in income or expenditure at another location or sector.

Whereas economic theory has proposed objective criteria to rank projects or alternative actions in terms of efficiency, no such objective criteria are available for distribution consequences. Thus, while one program or public investment alternative can be said to be more efficient than another and hence, more desirable from an economic standpoint, economists have no objective basis for judging one distributional outcome to be superior to another. Distributional consequences and economic impact are important inputs to decision-making and must be a part of an economic analysis, but the analysis itself may not provide unequivocal conclusions or recommendations about which option is "best" from a distributional standpoint.

Consequently, information on the relative importance or the social value of the physical effects of acid deposition is necesary to determine whether one level of control or protection is economically efficient. Such information is also necessary to determine the distributional impacts of the phenomenon and its control. Estimation of the monetary values of the various physical effects is one means of determining the relative importance of the different effects and consequences. In addition, monetary values of the loss of fish, damages to vegetation or a more frequent repair of buildings provide a common denominator that permit aggregation of dissimilar physical effects and comparisons with cost of control estimates.

Information on the incidence or distribution of costs and benefits among regions, among social groups and even among different generations will be useful to policy development in at least two ways. First, it will enable governments to assess the equity of policies intended to resolve the problem and the extent to which extra costs may have to be incurred to achieve equity. Second, an understanding of the distribution of costs and benefits will indicate how much cost or benefit are imposed on or enjoyed by various groups or sectors associated with the problem. This will indicate whether these parties will have economic incentives to comply with or resist abatement efforts. The higher the costs, the more incentive a polluter has to resist compliance. The likely reaction of these groups to policies can then be postulated. Most importantly this information can be used to design policies that can more effectively induce the relevant firms or individuals to change their behavior in an environmentally desirable manner.

A greater understanding of the economic implications associated with acid precipitation and its

control can thus help governments make decisions concerning the first dilemma: how much effort and resources should ultimately be devoted by all governments to emission controls and/or "defensive measures"? The economic efficiency criterion suggests that abatement efforts be undertaken to the point where extra costs are equal to the extra benefits of such efforts or programs. Moreover, environmental protection and pollution control measures employed to attain given levels of pollution control should be least-cost or cost-effective. These criteria provide guidance for decision-making although other factors in addition to economic consequences are likely to be considered by governments and public agencies.

As noted, economic studies provide frameworks with which policy-makers can postulate, analyze and evaluate alternative control scenarios. In this way, the second dilemma can be addressed. That is, how should Canada and individual provinces best allocate their limited resources if U.S. emissions are not controlled to any significant degree? Economic criteria suggest that the most highly valued resources and uses be protected first.

These are the reasons for investigating the economic as well as the physical dimensions of the acid precipitation problem. The next section will show how we have undertaken to obtain the required information. The methods and approaches being applied will be described and the reasons why they were chosen will be given. In doing so, some insights we have gained in the course of undertaking these studies will be noted.

## III. WHAT ONTARIO IS DOING TO STUDY THE ECONOMIC IMPLICATIONS OF ACID PRECIPITATION

It should be noted that much of the $5 million dollar per year research effort by the Ontario Government is directed at determination of the physical effects and relationships associated with acid precipitation. The principal focus of this research is substances that are deposited in the form of dry particulate matter or in snow and rain that cause environmental acidification. The overall Acid Precipitation in Ontario Study (APIOS) research program consists of the components summarized in Table 1. In addition, the Federal Govern- ment of Canada has an acid precipitation research program of its own underway. The Ontario Government, the Federal Government and the governments of other provinces in eastern Canada are coordinating these efforts through Federal-Provincial Committees and joint studies. Finally, research and

TABLE 1

PRINCIPLE COMPONENTS OF THE ACID PRECIPITATION IN ONTARIO STUDY

1. Determination of the effects of atmospheric deposition on aquatic ecosystems including:

   - water quality
   - phytoplankton
   - zooplankton
   - fish communities

2. Determination of the effects of atmospheric deposition on terrestrial ecosystems including:

   - soil biogeochemistry
   - vegetation regimes

3. Determination of the mechanisms and quantitative dimension of the emissions, atmospheric transport and deposition of acids, acid forming materials and other substances. This task includes:

   - Emissions Inventory
   - Atmospheric Modelling and Meteorology
   - Deposition Monitoring Networks

4. Development and the investigation of interim defensive actions or methods and programs to mitigate the effects of acid deposition and to preserve, protect or rehabilitate affected ecosystems, both aquatic and terrestrial, with respect to:

   - technical feasibility (will the methods work?)
   - economic feasibility (do the benefits exceed the costs?)

. . .continued/

TABLE 1 (cont'd)

5. Determination and assessment of the socio-economic implications associated with acid precipitation including:

   - assessment of the economic effects of acid precipitation and the benefits of control strategies.

   - assessment of the costs of emission control strategies and interim mitigative actions to protect or rehabilitate ecosystems.

   - development of techniques or tools to help evaluate various strategies to deal with or resolve the problem.

regulatory efforts in the U.S. and Canada are being coordinated through bilateral Work Groups under the auspices of the Memorandum of Intent on Transboundary Air Pollution.*

The socio-economic research component of the APIOS program consists of the three inter-related aspects listed in Table 2.

While pollution abatement investments often generate hard to discern public benefits that are widely dispersed over many individuals or regions, the private costs of controls and abatement efforts are usually more visible and are generally concentrated on particular industrial sectors, firms or individuals. Consequently assessment of the public benefits of acid precipitation control measures is an important focus of the socio-economic component of the APIOS.

Measurement of the private costs of pollution control is a relatively easy task compared to the estimation of the public benefits of abatement actions. This latter task requires the application of techniques and methods which are not well understood by the public and whose results are, understandably, not yet widely accepted by administrators. Nevertheless, a systematic framework for the quantification of the effects of environmental pollution and estimation of the value of these effects to society exists and can yield useful information.

The basic framework for determining the public damages of pollution as well as the public benefits of its control consists of the four components or linkages listed below.

(1) Acid precipitation (or any other environmental disruption) causes physical and ecological effects on various environmental resources and receptor categories - i.e. what is the physical dose-response relationship for each receptor category?

(2) Definition of the populations of resources, people or features at risk. This risk may extend over geographical areas, over social or economic groups and/or over time.

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*There are three Work Groups. Group I is concerned with the Assessment of Environmental Impacts. Group II is directed at Atmospheric Modelling. Group III-A is developing Control Strategies and Group III-B is investigating Control Costs and Emissions Data. All are producing reports.

TABLE 2

PRIMARY COMPONENTS OF THE SOCIO-ECONOMIC RESEARCH PROGRAM ON ACID PRECIPITATION IN ONTARIO

(1) Assessments of the social and economic effects of acid precipitation and the benefits of reducing these effects in Ontario.

(2) Assessments of the costs and other implications of $SO_2$ and $NO_x$ controls as well as the costs of "defensive actions" to offset the effects of acidification on terrestrial and aquatic ecosystems.

(3) The development of techniques and tools to aid in the evaluation of strategies to deal with or resolve the problem.

(3) Physical or ecological effects result in changes in human activities, perceptions, uses and valuations of the environmental resources and receptor categories.

(4) Changes in human activities, perceptions and uses result in changes in economic values some of which are measurable in monetary units.

The first step in this framework is to identify all of the physical and ecological effects that are relevant to the problem. These effects can be listed on the basis of receptor categories as is shown in Table 3. Inventory data to determine the resources and populations at risk are required next. Then, the possible effects on human uses are identified as shown in Table 4. The responses which people make to the physical and ecological effects will be registered through these uses.

The fourth step in the framework is the valuation of the responses people make or changes in the values people have for the physical and ecological damages or effects. To do this, two basic types of values are noted. First, many of the resources that are affected are used to produce goods and services that are sold in markets. Market prices can be used to estimate the value of the losses or gains resulting from the environmental effects. These values are called financial or market values. The price of fish caught and sold by commercial fishermen indicates the amount people are willing to pay for the fish for food under the prevailing market conditions.

However, for some uses, no markets exist so that market prices are not available to estimate monetary values. People are nevertheless willing to pay something for these unmarketed goods and services. It requires specialized techniques to discover how much.

In addition, there is a strong likelihood that people value many of the resources and the uses listed in Table 3 and 4 over and above what they spend on them. For example, a recreational angler may spend a measurable amount of money on fishing but might, if required, be willing to pay much more for the right to fish. Likewise, the financial value of sickness caused by pollution can be measured by the amount of money spent on health care and lost wages. The unfortunate individual might, however, be willing to pay far more to

TABLE 3

RECEPTOR CATEGORIES OR SECTORS WHICH MIGHT BE AFFECTED BY ACID PRECIPITATION

A. Terrestrial Systems
   1. Forests
   2. Soils
   3. Wildlife and Waterfowl
   4. Crops and livestock.

B. Aquatic Systems
   1. Water quality
   2. Fish populations
   3. Zooplankton
   4. Micro and macro flora

C. Visibility

D. Human Systems
   1. Structures and materials
   2. Historical structures and artifacts
   3. Water supply systems

E. Human Health
   1. Through direct ingestion of water or fish
   2. Water contact sports

T A B L E 4

USES OF SECTORS WHICH
MIGHT BE AFFECTED BY ACID PRECIPITATION

A. Terrestrial Systems

1. Forests

(a) Recreation
(b) Pulp and paper
(c) Lumber
(d) Sugar maples
(e) Firewood

2. Wildlife

(a) Hunting
(b) Photography
(c) Commerical fur
(d) Hides and meat for subsistence

3. Agricultural production

4. Ornamental Plants

B. Aquatic Systems

1. Fisheries

(a) Recreational fishing
(b) Commercial fishing
(c) Subsistence (Native) fishing

2. Recreational uses of water

(a) swimming
(b) waterskiing etc.
(c) scuba diving
(d) boating

. . .continued/

C. Visibility

1. Viewing scenery

2. Aircraft traffic control

D. Human Systems

1. Structures and Materials

(a) Repair and maintenance
(b) Replacement

2. Historical Structures

(a) Repair and maintenance

3. Water Supplies

(a) Water Treatment
(b) Corrosion

E. Human Health

1. Morbidity

2. Mortality

3. Worker productivity

avoid getting sick in the first place. Finally, the financial value of the forests can be measured by the price of wood and other products that can be produced. Society, however, may be willing to pay substantially more than the price of lumber or pulp wood to ensure that certain other, unmarketed, services of the forest such as its water holding capacity, shade, support of wildlife, soil conservation and as a legacy to future generations, be maintained and preserved.

The monetary values that people have for environmental features and the various receptor categories listed in Table 3 and the uses listed in Table 4 that are over and above what can be measured with market prices and transactions are called amenity values (Maler and Wyzga, 1976). Other writers have used the terms option value, legacy value or non-use value. The value that people ascribe to environmental damages or improvements is, therefore, the sum of the financial and the amenity values.

While there is agreement among economists as to the correct theoretical measure of financial and amenity values, such agreement does not exist about which methods yield the most accurate and credible empirical estimates of these values (Freeman, 1979). Moreover, the physical relationships between acid deposition and many of the various receptors categories in Table 3 and uses in Table 4 are not yet well established. Finally, data on the amounts of resources or receptor actually being damaged or affected are not readily available. Consequently, the emphasis in the current Ontario Government studies is on the development of methods and procedures that can be updated rather than on the estimates of physical quantities and economic values per se.

The values that have just been discussed refer to increases or decreases in economic welfare to society as a whole. If they can be measured properly, they can then be compared with the costs of controls to ascertain the degree of economic effficiency of the control effort. Another important economic consequence is the economic impact of expenditures in particular locations or communities. These expenditures may not constitute a loss or a gain to society as a whole since a loss in one location may be perfectly offset by a gain in another. However, this information is important to determine how the local economy of a particular place might be affected and, therefore, is important for equity considerations.

Three interrelated studies are being undertaken to develop methods that will help us to estimate the economic changes and regional impacts that can result from acid precipitation and its control:

(1) The Amenity Value Survey Study

A direct survey of 900 respondents to determine individuals' willingness-to-pay to preserve natural ecosystems from the effects of acidification will be conducted in Muskoka-Haliburton (a vacation area in Ontario whose lakes are sensitive to acidification), the Kawarthas (a vacation area whose lakes are not sensitive to acidification), and an urban area (Kitchener, Ont.). The survey will also obtain information on respondents' attitudes, perceptions and activity responses to acid precipitation effects.

Consultant: ARA Consultants, Toronto

(2) Tourism and Recreation Study

An assessment of the Economic Significance of Acid Precipitation on Tourism and Outdoor Recreation in Ontario. A framework or model is being developed for estimating the effects of acidification on recreational resources (fish, water quality, etc), the response of users (i.e. anglers and swimmers) to these changes and the expenditures implied by these changes. This model will be readily updatable. Preliminary estimates of physical and economic effects in six regions of the province will be made.

Consultant: Currie, Coopers & Lybrand, Toronto

(3) The Financial Value Study

Present and future damages to receptor categories such as forests, commercial fisheries, commercial fur bearing mammals, agriculture and human structures and materials that have market prices associated with them are being studied. An interactive

computerized procedure for generating and updating estimates is being developed. The physical dose-response relationships required to make estimates for these receptor categories are being postulated and relevant data are being collected.
Consultant: Victor & Burrell, Toronto

These studies will provide us with the procedures that can be improved and updated as physical relationships are established and new data are produced.

For the cost of control component of the program, a comprehensive investigation of the abatement options for the INCO and Falconbridge nickel smelting operations has been initiated under the auspices of a Task Force composed of representatives from the public and from the Ontario and the Federal governments. In addition, abatement cost information for the Ontario Hydro thermal power generating stations is being assembled.

Finally, as part of the socio-economic research component, a computerized procedure is being developed that will permit researchers and administrators to postulate deposition objectives and emission control scenarios throughout eastern North America and then calculate the least-cost configurations of emission controls for specific point sources. This "screening model" will employ information from our cost of control studies and the long range transport models that has been developed by our Ministry and others.

None of these studies are as yet completed. Nevertheless, we have learned some interesting and important insights which will be discussed in the next section.

## IV. WHAT WE HAVE LEARNED SO FAR

The effects of acid precipitation on fisheries and outdoor recreation will be discussed in terms of the framework presented on page 7. Following this, some thoughts concerning the costs of controlling major $SO_2$ and $NO_x$ sources in North America will be noted.

(1) Damages and Benefits of Controls

Tourism ranks second in terms of Ontario's export industries (after transportation equipment) and constitutes an exceedingly important economic sector in the northern, central and eastern regions of the province (Ontario, Ministry of Industry and Tourism, May 1979, p.20). Outdoor recreation constitutes a substantial proportion of this activity. The many businesses and individuals who offer goods and services in support of these activities depend on Ontario's abundant water, forest and wildlife resources to sustain them.

(a) Physical Dose-Response and Identification of Resources and Populations at Risk*

The effects of acid precipitation on fisheries and tourism or outdoor recreation are limited by location and by recreational activity. The principal effects will be felt through aquatic systems with low buffering capacities. This means that lakes and streams in the highly buffered Southwestern part of the province and the Great Lakes proper are not, according to what is known at this writing, susceptible to acidification.

The recreational activities that can be affected are limited, so far as we know, to the aquatic-based activities listed in Table 5. According to the Tourism and Outdoor Recreation Planning Study Committee (September, 1978), these aquatic based recreational activities account for about 37% of all recreation activities undertaken by Ontario residents on weekend or vacation trips. However, these same 6 activities account for 51% of the total activities in which non-residents participated during their trips to Ontario.

The physical manifestations about which most is known at this time are direct toxicity to fish and reproductive failure of fish populations due to stresses caused by:

- long-term acidification of lakes and streams (resulting in elevation of aluminum and certain other elements to toxic levels);

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*Unless otherwise referenced, the material in this Section is based on information and data found in U.S.-Canada, Memorandum of Intent, Impact Assessment, February, 1981.

T A B L E 5

AQUATIC-BASED OUTDOOR RECREATIONAL ACTIVITIES THAT ARE POTENTIALLY SUSCEPTIBLE TO ACID PRECIPITATION WITH NATURE OF PHYSICAL EFFECT AND IMPLICATIONS

| | Activity | Physical Effect | Implications for Recreation |
|---|---|---|---|
| 1. | Fishing | - toxicity stresses and mortality<br>- reproductive failures<br>- food chain | - reduced quantity and quality of fishing |
| 2. | Swimming ) | - no known health effects | |
| | ) | - initially clearer water | - initially enhanced |
| 3. | Water Skiing ) | - subsequently troublesome aquatic vegetation | - ultimately degraded |
| | ) | | |
| 4. | Scuba Diving ) | | |
| 5. | Boating | - no known effect | |
| 6. | Waterfowl hunting | - food chain | - possible reduction in available breeding areas |
| 7. | Moose hunting | - food chain | - may reduce area of suitable habitat |

- short-term, seasonal "acid pulses" that come with spring melts or severe storm run-off

Fish populations may also be stressed because of reductions in food organisms caused by acidification.

Long-term acidification may also affect waterfowl and moose populations through the respective food chains of these organisms although these relationships have not been confirmed.

Available information to date indicates that there are no health effects from direct contact with acidified water during swimming, water skiing or diving. There are, however, two possible health concerns that could be attributed to acidification.

- contamination of edible fish by toxic materials, principally mercury;

- leaching and corrosion of water storage and distribution systems leading to elevated levels of toxic elements in water supplies.

Swedish researchers have reported that, as lakes become acidified, aquatic weeds and plants are reduced and, except for a few acid resistant species such as sphagnum moss, are eliminated altogether. This initially enhances water quality for contact activities. However, under acid condition, decomposition is slowed to a virtual standstill and a mat of scenescent, undecomposed vegetation forms on the lake bottom. This material, when stirred up, can reduce the quality of the water contact experience.

In addition, an odour-causing planktonic prymnesiophyte alga, (chrysochromulina breviturrita, Nich.) has been found in some Ontario lakes with pH in the range of 5.5 and 6.2. Although the relationship between lake acidification and the proliferation of this species has not been proven, data collected thus far show that the growth of this species, and the serious "rotten cabbage" odour associated with it, is restricted to acid lakes.

The physical effects relevant to each recreational activity and the implications for the activity are summarized in Table 5.

Quantitative dose-response relationships between acidification and waterfowl and moose are lacking and are needed. The dose-response relationship between acidification and fish productivity needs refinement and verification so that it can be used for prediction purposes.

(b) Human Responses to Physical Effects

If acidification proceeds unabated and fish, moose or waterfowl populations are substantially reduced, it is not yet clear what people will do. Will they stop fishing or hunting but carry on some other activity in the same location? Will people go somewhere else to participate in the same activities? If people do not leave the area, then losses in expenditure and regional impact will not necessarily be experienced. There will, however, be important amenity losses if fishing or hunting is diminished. If people shift, say from fishing to swimming, then there may be a reduction in expenditure in the local area because people spend more money on fishing than they do on swimming. If people actually leave the province to try to find better fishing or hunting, then the loss to Ontario would at least be equal to their expenditures. Otherwise, as long as people stay in the province, there may be no net expenditure loss to the provincial economy. However, businesses that supply recreational goods and services and particular regions may sustain income losses as people shift to other activities or to other locations.

In sorting out recreationists' responses to the physical effects, other factors that influence future growth in tourism and recreational activity must be taken into account. These factors include:

(1) population growth and age structure;

(2) leisure time availability;

(3) trends in activity participation;

(4) disposable income;

(5) foreign exchange differentials;

(6) prices and availability of complementary and substitute goods and services such as gasoline.

Because there are offsetting forces operating with respect to tourism demand in Ontario it does not appear that tourism will grow substantially in the foreseeable future (R. Simpson, Currie, Coopers and Lybrand Ltd., personal communication). Thus, a factor such as acid precipitation, which might cause a reduction in recreation participation, cannot be quickly offset by annual growth. Cost/price squeezes and other economic forces are affecting resorts and lodges in Ontario as well as other business so it is particularly difficult at this time to isolate the impacts of a single, highly insidious, phenomenon such as acid precipitation from these other forces.

Similarly, demand for cottage and lakeshore property and their prices are overwhelmingly influenced by the proximity to urban areas and access. Income, interest rates and travel costs are also significant factors in cottage property demand and prices. Water quality has not yet been shown to be a significant factor in cottage property values.

Nevertheless, additional detrimental stresses like acid precipitation can only aggravate the problems faced by businesses dependent on tourism and outdoor recreation.

(c) Valuation of the Human Responses

The value of the changes in human uses and perceptions wrought by acid precipitation is measured in theory by individuals' willingness-to-pay to obtain the uses and services of a cleaner environment. The amounts people would require in compensation to relinquish the uses and benefits obviated by pollution is another theoretically appropriate measure. These measures may be estimated empirically by a variety of methods including those which produce estimates of financial and amenity values. Expenditures on recreational activities constitute one estimate of the amounts people are willing to pay for these activities. People may, in fact, be willing to pay much more to engage in these activities than they actually spend. Moreover, some people may even be willing to pay an amount of money to have the option of engaging in these activities in the future.

With respect to users, a fundamental question is how much people will reduce their fishing effort or stop fishing altogether in

acidified areas as a result of reductions in fish populations. Moreover, to what extent will people curtail or stop swimming and go on to other activities in the same or different areas? Estimates of the changes in expenditures implied by these behavioral changes are being prepared although it is emphasized that the key output of our studies will be the procedures or models that can be improved or re-estimated as new information becomes available.

A last point is that fisheries and outdoor recreation are only two of the sectors or receptor categories being examined. The other categories listed in Tables 3 and 4 are also being affected and all effects must be summed to obtain aggregate levels of damages.

(2) Costs of Emission Controls and Defensive Actions

In 1979, US sources generated about 29.7 million metric tonnes per year of sulphur dioxide ($SO_2$) to Canada's 5.3 million metric tonnes (U.S. Canada, Engineering, Costs and Emissions, Jan. 15, 1981, p. 14). About 22.3 million tonnes of nitrogen oxide ($NO_x$) came from U.S. sources while 2.2 million tonnes were generated from Canada during the same year.

The principal sources of $SO_2$ emissions in the U.S. are electric power utilities which account for almost 70% of the total. In Canada, non-ferrous smelters produce better than 40% of the total $SO_2$ emissions with the remainder coming from industrial sources. Automobile emissions are the major source of $NO_x$ in both countries.

The methods to reduce $SO_2$ emissions are the use of low sulphur fuels, the removal of sulphur from fuels or sulphur-bearing ores prior to combustion (i.e. coal washing) and Flue Gas Desulphurization (FGD). There are a variety of FGD technologies available ranging from "wet scrubbing" which removes the sulphur chemically and generates a troublesome sludge, to the production of sulphuric acid as a saleable by-product.

There are somewhat fewer technical options to control $NO_x$ in power plants and industrial sources. Some of these techniques, however, introduce hazards into boiler operation and may be incompatible with $SO_2$ abatement technologies.

A key issue in the U.S. is the cost of achieving $SO_2$ reductions by the electric utilities. The arguments of utility spokesmen and their allies in the coal industry and some midwestern State Governments is that $SO_2$ emissions reductions will necessitate switching to low sulphur western coal and, in many cases, the installation of expensive FGD systems. They allege that the first alternative would put coal miners out of work and cause huge financial losses in the coal industry in such states as Indiana, West Virginia, Ohio and Illinois (Wooton, 1981). The installation of FGD systems would significantly burden the already overburdened financial position of the utilities. The spectre of rising power rates and unemployment by power users is raised as well. The spokesmen for these interests top off their arguments with the assertion that the association between acid deposition and $SO_2$ emissions is not conclusively proven anyway so that no abatement action should proceed until absolute proof is established (Dowd, April 1981).

In Canada, the non-ferrous smelters and other $SO_2$ sources are faced with disposing of the large increases in sulphuric acid that will likely be produced as a by product of abatement. The challenge is finding markets for this acid without disrupting existing patterns of trade or precipitating severe declines in the price of sulphuric acid.

A number of estimates of emission control capital costs have been published in the media. These range from the hundreds of millions to billions of dollars. These estimates are, by and large, useless for anything except press copy. What is useful and what we are developing for Ontario sources are estimates of the capital and operating costs of achieving various, technically feasible, levels of emissions; from the current levels down to zero emissions in some instances. With this type of information, comparisons with benefits can be made and assessment of the impact of such costs can be undertaken.

Because of their monopoly positions, electric utilities in Canada and the U.S. can generally pass on most, if not all, of their cost increases to their customers, subject to approval by State or Provincial regulatory agencies. From an economic efficiency point of view, this is as it should be. Those consumers who enjoy the benefits and services of electricity should pay the full costs of power production, including

environmental damage costs. From an equity standpoint, however, some groups or regions are likely to be hit harder than others. Investigations sponsored by the Canadian federal government and by ourselves are tracing the magnitudes and the incidence of the economic repercussions of control costs through our economy. On this point, I have argued elsewhere that the macro-economic effects of environmental expenditures in the U.S. and Canada on inflation, unemployment, economic growth, productivity and international competitiveness are detectable, but insignificant (Donnan, 1981). Some disproportionate cost burdens will likely fall on individual firms or industries but, in many cases, the implications of these costs have been exaggerated. In any event, the economic impacts of control costs are being addressed in detail by governments on both sides of the border.

Finally, the economic and technical feasibility of liming to protect and rehabilitate sensitive and acidified lakes and streams is being studied in Ontario. The results of these investigations will not, however, be available for some time.

## V. WHERE DO WE GO FROM HERE?

There is clearly much to be done before we can begin to evaluate control strategies and programs with the sophistication that we would envision. Once our first set of investigations has been completed and we have our methodologies in hand, we can then begin to generate quantitative estimates of physical damages, control costs and benefits. Various programs or scenarios can then be reviewed and discussed. However, certain information and data are needed from physical and biological studies in order to refine our methods and models and to make more credible estimates of damages and the benefits of controls and protection programs. Some of these data requirements have been mentioned earlier in the paper but they bear repeating.

(1) Relationships between emissions and acid deposition (wet and dry) must be empirically established.

(2) The relationship between acid deposition and the rate of acidification in soils and water

bodies would be helpful. (these are the subject of current research efforts).

(3) Quantitative physical dose-response relationships between acidification and the various plants and animals that are important and valuable to people. In particular:

- fish productivity
- waterfowl and moose
- tree growth and wood yield
- maple sap production

(4) Inventory data on the various resources and populations that are at risk as noted in Table 3.

(5) Verification of assumptions about the human responses to physical effects. For example, what will people do as fishing quality declines or disappears? Will repairs, maintenance or replacement of damaged structures and materials actually be undertaken?

In conclusion, we believe that the methods we are developing, especially for the measurement of the physical and economic damages of acid precipitation, will be applicable in other areas of the country and to other types of environmental disruptions. Economists and administrators working in this field must eventually come to a consensus as to which methods should be used to generate acceptable estimates of the economic value of the environmental damages from pollution and the benefits of environmental protection programs. Such estimates will never be accurate to the first decimal point but agreement on which methods are most appropriate for specific situations will go a long way, I believe, in making the results of these studies credible and useful.

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